PATENT
450117-03249

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR LETTERS PATENT

TITLE: PILOT PATTERN DESIGN FOR A STTD SCHEME IN AN OFDM SYSTEM

INVENTORS: Zhaocheng WANG, Richard STIRLING-GALLACHER

William S. Frommer
Registration No. 25,506
Dennis M. Smid
Registration No. 34,930
FROMMER LAWRENCE & HAUG LLP
745 Fifth Avenue
New York, New York 10151
Tel. (212) 588-0800

Sony International (Europe) GmbH
PAE00-042TRDE
Our File: P23767EP

Pilot pattern design for a STTD scheme in an OFDM system

The present invention relates to a transmitting device and a receiving device of a wireless orthogonal frequency division multiplex (OFDM) communication system with space time transmit diversity (STTD). Further, the present invention relates to a channel estimation method for performing a channel estimation in a wireless OFDM communication system in which a transmitting device comprising a first and a second antenna transmits signals with space time transmit diversity.

In wireless telecommunication, the transmission quality between a transmitting device, such as a base station, and a receiving device, such as a mobile terminal, depends strongly on the respective transmission environment and is often deteriorated by fading effects and the like. This often leads to poor speech and data transmission quality, particularly if only one single antenna is used on the transmission side and one single antenna is used on the receiving side. Therefore, some mobile terminals for wireless telecommunication systems, such as the GSM system, comprise two or more and different kinds of antennas built as internal or external antennas in the mobile terminal. However, it is desirable that modern mobile terminals are as small and light as possible and therefore it is an increasing interest to use only a single antenna in these mobile terminals. In order to allow the use of only a single antenna on the receiving side, particularly the mobile terminal side, it has been proposed to use more than one antenna on the transmitting side, particularly the base station side, so that the diversity gain can be used for a better transmission quality. This scheme is called transmit diversity. Transmit diversity generally means that more than one antenna, e.g. two antennas, transmit data simultaneously to a receiving device. If the same data are transmitted in parallel by two antennas, the receiving side has a chance to receive signals at least from one of the antennas with an acceptable transmission quality so that a good connection can be ensured. One specific approach in the transmit diversity scheme is the use of a so-called space time coding. The resulting space time transmit diversity (STTD) has been adapted and is part of the UMTS standard for the next generation of mobile telecommunication.

In a space time transmit diversity system, a transmitting device, such as a base station, comprises e.g. two antennas arranged spaced apart from each other in a space diversity arrangement. A stream of data to be transmitted to a receiving device, such as a mobile terminal, is encoded and processed so that two parallel data streams are generated.

After further processing corresponding to the respective wireless communication system, the data of each of the two data streams are transmitted by a respective one of the two antennas. Although generally the same data content is transmitted by each of the two antennas, the signals transmitted by the two antennas are not absolutely identical, but data symbols to be transmitted are mapped or coded slightly differently on the signals transmitted by each of the antennas. This allows a receiving device receiving the signals transmitted from the two antennas with only a single antenna to distinguish and separate signals coming from one of the transmitting antennas from signals coming from the other of the transmitting antennas. Since the two transmitting antennas are arranged in a space diversity arrangement, cross interference is avoided and the receiving device can then, after a corresponding channel estimation, distinguish and combine the signals from the two transmitting antennas to obtain a better transmission quality. The channel estimation in the receiving device is usually performed on the basis of pilot symbols transmitted from the transmitting device. The receiving device performs a channel estimation by comparing received pilot symbols with an expected pilot symbol to measure the channel response and to tune the receiving device to the best transmission channel, i.e. the transmitting antenna to which the better connection exists.

The above-mentioned UMTS system bases on a code division multiple access (CDMA) scheme. The CDMA scheme is only one of several possible multiple access schemes used in wireless telecommunication. For wireless telecommunication with high data rates, the orthogonal frequency division multiplex (OFDM) scheme is known, in which the available frequency band used for a communication is divided in a plurality of frequency subcarriers, whereby adjacent frequency subcarriers are respectively orthogonal to each other.

The object of the present invention is now to propose a transmitting device and a receiving device for a wireless OFDM communication system with space time transmit diversity as well as a channel estimation method for such a communication system, which allow a simple and effective channel estimation to be performed.

This object is achieved by a transmitting device for transmitting signals in a wireless OFDM communication system with STTD according to claim 1. The transmitting device according to the present invention comprises encoding means for encoding a data stream on the basis of a STTD scheme and outputting a first and a second STTD encoded data stream, a first and a second antenna means for transmitting the data of the first and the second data stream, respectively, in OFDM signals, said first and said second antenna means being arranged spaced apart from each other in a space diversity

arrangement, pilot symbol generating means for generating pilot symbols to be transmitted among said data of said first and second data stream, whereby first pilot symbols are transmitted via the first antenna and second pilot symbols are transmitted via said second antenna, some of said second pilot symbols being orthogonal to corresponding ones of said first pilot symbols.

The above object is further achieved by a receiving device for receiving signals in a wireless OFDM communication system with STTD according to claim 8. The receiving device according to the present invention comprises a single antenna means for receiving STTD encoded signals transmitted from a first and a second space diversity antenna means of a transmitting device of the OFDM communication system, said first and said second space diversity antenna means transmitting corresponding pilot symbols in said STTD encoded signals, whereby at least a part of the pilot symbols transmitted from the second antenna means is orthogonal to corresponding pilot symbols transmitted from the first antenna means, processing means for detecting pilot symbols in the received STTD encoded signals, for processing detected pilot symbols and performing a channel estimation on the basis of said processing to separately determine the transmission quality of STTD encoded signals transmitted from said first and said second antenna means, respectively.

Further, the above object is achieved by a channel estimation method according to claim 13 for performing a channel estimation in a wireless OFDM communication system, in which a transmitting device comprising a first and a second antenna transmits signals with STTD, said first and said second antenna means being arranged spaced apart from each other in a space diversity arrangement, whereby the channel estimation method comprises the steps of transmitting first and second pilot symbols via said first and said second antenna means, respectively, some of said second pilot symbols being orthogonal to corresponding ones of said first pilot symbol, receiving said pilot symbols in a single antenna of a receiving device, processing received pilot symbols and performing a channel estimation on the basis of said processing to separately determine the transmission quality of STTD encoded signals transmitted from said first and said second antenna means, respectively.

The proposed scheme of transmitting, receiving and processing first and second pilot symbols allows a simple and effective channel estimation processing to be performed on the receiving side so that a better coherent demodulation of the transmission channel can be performed to ensure the best transmission quality. Particularly, the present invention ensures full space and time diversity. Further, no feedback information from the receiving side to the transmitting side is required and an improved data transmission

capacity can be realised. Further, the proposed system is robust to transmission antenna failures and guarantees power amplifier balance on the transmitting side.

Further advantageous features are claimed in the respective subclaims.

Advantageously, the corresponding first and second pilot symbols transmitted from the first and the second antenna means of the transmitting device, respectively, have the same frequency and time allocation in the OFDM system. In other words, corresponding first and second pilot symbols are transmitted in the same subcarrier and in the same time slot of the OFDM system. Hereby, the first and the second pilot symbols advantageously are alternatively identical and orthogonal to each other in the frequency as well as in the time dimension. This means that in the frequency and time grid of the OFDM system, identical first and second pilot symbols and orthogonal first and second pilot symbols alternate with each other in the frequency as well as in the time dimension.

It has to be clarified at this point that the single antenna of the receiving device receives the first pilot symbols transmitted from the first antenna means and the second pilot symbols transmitted from the second antenna means of the transmitting device only as a combined or superimposed pilot symbol. In case that the first pilot symbol and the second pilot symbol transmitted in the same frequency subcarrier and the same timepoint are identical, the receiving device receives a combined pilot symbol comprising the superimposed identical first and second pilot symbol. In case that the first and second pilot symbol are orthogonal to each other, the receiving device receives a combined pilot symbol comprising the superimposed orthogonal first and second pilot symbol. In the receiving device, the transfer function of the first and the second pilot symbol, respectively, can therefore be separated so that the respective channel estimation for each of the two transmission antennas can be performed in a simple way.

Advantageously, the second pilot symbols alternately have the identical and the inverse complex value of the corresponding first pilot symbol in the time as well as in the frequency dimension, so that the processing and the channel estimation on the receiving side can be performed on a basis of a simple addition and subtraction calculation of the received pilot symbols. On the basis of the channel estimation result, both the STTD encoded signals from the first antenna means and from the second antenna means of the transmitting device are further processed and used as the communication data in the receiving device.

The transmitting device according to the present invention can e.g. be implemented in the base station of a OFDM communication system and the receiving device according to the present invention can e.g. be implemented in a mobile terminal of a OFDM communication system.

In the following description, the present invention is explained in more detail in relation to the enclosed drawings, in which

figure 1 shows schematically a base station comprising a transmitting device according to the present invention,

figure 2 shows schematically a mobile terminal comprising a receiving device according to the present invention,

figure 3A and 3B a first and a second example, respectively, of a pilot symbol pattern transmitted by a first antenna means of a transmitting device according to the present invention, and

figure 4A and 4B a first and a second example, respectively, of a pilot symbol pattern transmitted by the second antenna means of the transmitting device according to the present invention.

In figure 1, the block diagram of a base station 1 of a wireless orthogonal frequency division multiplex (OFDM) communication system is shown, which comprises a transmitting device according to the present invention. It is to be understood that in figure 1 only elements important for the understanding of the present invention are shown. Further elements, such as coding means, modulation means, RF part and the like necessary for the operation of the base station are omitted for the sake of clarity.

The base station 1 comprises a first antenna 5 and a second antenna 6 being arranged spaced apart from each other in a space diversity arrangement. Therefore, the first antenna 5 may also be called a non-diversity antenna and the second antenna 6 can also be called a diversity antenna. The space diversity arrangement of the first antenna 5 and the second antenna 6 is so that the two antennas 5 and 6 are sufficiently separated in space, so that the signals transmitted by the first antenna 5 and the second antenna 6, respectively, are uncorrelated and an effective diversity gain can be achieved on the receiving side.

Further, the base station 1 comprises a encoding means 3 for encoding a data stream on the basis of a space time transmit diversity (STTD) scheme and outputting a first and a second STTD encoded data stream to a multiplexer 4. The first STTD encoded data stream is to be transmitted via the first antenna 5 and the second STTD encoded data stream is to be transmitted via the second antenna 6. Although the data transmitted from the first antenna 5 and the second antenna 6 are generally the same data, i.e. contain the data of the single data stream supplied to the encoding means 3, the data are not transmitted identically by the two antennas 5 and 6. For example, the data transmitted by the first antenna 5 identically correspond to the data arrangement of the single data stream supplied to the encoding means 3. If, e.g. a first data symbol S_1 in a time period 0-T and a second data symbol S_2 in the succeeding time period T-2T are supplied to the encoding means 3, the first data stream output by the encoding means can identically correspond to that arrangement (data symbol S_1 followed by data symbol S_2). The second data stream output by the encoding means 3, however, contains the data symbols S_1 and S_2 in a different arrangement. For example, as shown in figure 1, in the second data stream, the data symbol of the first time period 0-T could be the negative complex conjugated value of the second data block S_2 of the first data stream, i.e. $-S^*_2$. The next succeeding data symbol of the second data stream is the conjugated complex value of the first data symbol S_1 of the first data stream, i.e. S^*_1. Thus, the second data stream contains the identical data content as the first data stream, but in a different arrangement. A receiving device receiving the signals from the first antenna 5 and the second antenna 6 as superimposed signals is therefore able to clearly distinguish between the signals transmitted from the first antenna 5 and the signals transmitted from the second antenna 6 due to the space diversity arrangement and the different arrangement of the same data content. It is to be understood that the space time transmit diversity scheme shown in and explained in relation to figure 1 only serves as an example to explain the present invention. Any other STTD scheme for transmitting data via the first antenna 5 and the second antenna 6 can be applied.

The base station 1 further comprises a pilot symbol generating means 2 for generating pilot symbols to be transmitted among the data of the first and the second data stream by the first antenna 5 and the second antenna 6. Thereby, the pilot symbol generating means 2 generates and supplies different pilot symbol patterns to be transmitted via the first antenna 5 and the second antenna 6, respectively, to the multiplexer 4. The general idea of the present invention is that some of the pilot symbols transmitted by the first antenna 5 and the second antenna 6 are orthogonal to each other so that the cross-interference from both antennas 5 and 6 is eliminated, the signals from the first, (non-diversity) antenna 5 and the second (diversity) antenna 6 can be differentiated and

consequently a separate channel estimation for each antenna 5, 6 can be achieved in a receiving device.

Figure 2 shows a schematic block diagram of a mobile terminal 10 comprising a receiving device for receiving signals in a wireless OFDM communication system with STTD according to the present invention. Particularly, the mobile terminal 10 is adapted to receive signals from a base station 1 as shown in figure 1.

The mobile terminal 10 comprises a single antenna 11 for receiving STTD encoded signals as well as pilot symbols transmitted from the first antenna 5 and the second antenna 6 of the base station 1. Further, the mobile terminal 10 comprises a receiving means 12, which comprises e.g. the necessary RF part and the like. Further, the mobile terminal 10 comprises a demodulation means for demodulating signals received by the receiving means 12 via the antenna 11. It is to be understood that the mobile terminal 10 further comprises all necessary elements to be operated in the corresponding wireless OFDM system. However, these elements are not shown for the sake of clarity.

The mobile terminal 10 further comprises a processing means 14 for detecting pilot symbols in the signals received by the receiving means 12 via the antenna 11. The processing means 14 processes detected pilot symbols and performs a channel estimation on the basis of the processing to separately determine the transmission quality of the received signals transmitted from the first antenna 5 and the second antenna 6, respectively. In other words, by processing the received pilot symbols, which are combined pilot symbols comprising the first and the second pilot symbols simultaneously transmitted by the first antenna 5 and the second antenna 6, the processing means 14 is able to separately determine the transmission quality of the signals transmitted from the first antenna 5 and the transmission quality of the signals transmitted from the second antenna 6. On the basis of this channel estimation result, both the STTD encoded signals from the first antenna 5 and from the second antenna 6 are further processed and used as communication data in the mobile terminal 10.

As stated above, at least some of the second pilot symbols transmitted from the second antenna 6 are orthogonal to corresponding first pilot symbols transmitted by the antenna 5. The processing performed in the processing means 14 bases on this orthogonality of the first and the second pilot symbols and enables the separate channel estimation for the first and the second antenna 5 and 6, respectively. In relation to figures 3 and 4, a specific example for pilot symbol patterns to be transmitted by the base station 1 and to be received and processed in the mobile terminal 10 are proposed.

Figure 3 comprises two figures 3A and 3B. Figure 3A shows a first example of a pilot symbol pattern to be transmitted by the first (non-diversity) antenna 5 of the base station 1. The shown pilot symbol pattern has a regular distribution in the time and the frequency dimension of the OFDM system. The pilot symbols 20, 21, ..., 28 are always transmitted in the same frequency subcarriers and in equidistant timepoints. For example, the pilot symbols 20, 21 and 22 are transmitted in a first frequency subcarrier, whereby respectively four data symbols are transmitted between adjacent pilot symbols 20, 21 and 21, 22. Pilot patterns 23, 24 and 25 are transmitted in a second frequency subcarrier and the pilot symbol 26, 27 and 28 are transmitted in a third frequency subcarrier. Thereby, the pilot symbols 20, 23 and 26 are transmitted at the same first timepoint, the pilot symbols 21, 24 and 27 are transmitted in the same second timepoint and the pilot symbols 22, 25 and 28 are transmitted in the same third timepoint. Thus, always the same frequency subcarriers are used for the transmission of the pilot symbols and the transmission of the pilot symbols in the respective subcarriers always takes place at equidistant timepoints. Such a pilot symbol pattern is known from prior art OFDM systems. On the receiving side, the channel estimation for the data symbols between adjacent pilot symbols (in frequency and time) is performed by e.g. linear interpolation. For example, for the data symbols between the pilot symbols 20 and 21 in the same frequency subcarrier, a linear interpolation of the pilot symbols 20 and 21 is performed on the receiving side. For the data symbols between the adjacent pilot symbols 20 and 23 received at the same timepoint but in different frequency subcarriers, a linear interpolation is also performed. For data symbols in frequency subcarriers, in which no pilot symbols are transmitted, a combination of a time and a frequency interpolation of the respective adjacent pilot symbols is performed.

Figure 3B shows also a regular distribution of the first pilot symbols to be transmitted by the first antenna 5 of the base station 1. The difference to the pilot symbol pattern of figure 3A is here that the (in time) succeeding pilot symbols are not transmitted in the same frequency subcarrier as the preceding pilot symbol, but in the immediately adjacent subcarrier. For example, the pilot symbol 31 is not transmitted in the same frequency subcarrier as the preceding pilot symbol 30, but the immediately adjacent (lower) frequency subcarrier. This pilot symbol pattern may allow a more accurate channel estimation for data symbols of frequency subcarriers, in which no pilot symbols are transmitted. Identical to the pilot symbol pattern proposed in figure 3A, the pilot symbols of the pilot symbol pattern proposed in figure 3B are also transmitted at identical timepoints. Thus, pilot symbols 30, 34 and 38 are transmitted at the first identical timepoint, pilot symbols 31, 35 and 39 are transmitted at the same second timepoint, pilot symbols 32, 26 and 40 are transmitted at the same third timepoint and pilot symbols 33, 37 and 41 are transmitted at the same fourth timepoint.

Figure 4 comprises two figures 4A and 4B, whereby figure 4A shows the pilot symbol pattern for the second pilot symbols to be transmitted by the second antenna 6 of the base station 1, which corresponds to the pilot symbol pattern of the first pilot symbols shown in figure 3A. As can be seen, also the pilot symbol pattern of figure 4A shows a very regular distribution of pilot symbols 42, 43, ..., 53 in frequency and time. The second pilot symbols are always transmitted in the same frequency subcarrier and at the same timepoint as the corresponding first pilot symbol. For example, the second pilot symbol 42 is transmitted in the same frequency subcarrier and at the same timepoint as the corresponding first pilot symbol 20. The second pilot symbol 43 is transmitted in the same frequency subcarrier and at the same timepoint as the first pilot symbol 21. The second pilot symbol 46 corresponds to the first pilot symbol 23, the second pilot symbol 50 corresponds to the first pilot symbol 26 and so on. Thereby, the second pilot symbols of the pilot symbol pattern in figure 4A are alternatingly identical and orthogonal to the corresponding first pilot symbols of the pilot symbol pattern shown in figure 3A. The second pilot symbols 42, 44, 47, 50 and 52 are identical to their corresponding first pilot symbols 20, 22, 24, 26 and 28. However, every other second pilot symbol (in time and frequency dimension) is the inverse complex value of the corresponding first pilot symbol. For example, a second pilot symbol 43 is the inverse complex value of the first pilot symbol 21, the second pilot symbol 46 is the inverse complex value of the first pilot symbol 23. The same is true for the second pilot symbol 48 and the first pilot symbol 25 and the second pilot symbol 51 and the first pilot symbol 27. Thus compares of adjacent second pilot symbols, as e.g. the second pilot symbols 42 and 43 as well as the second pilot symbols 42 and 46 are orthogonal to the corresponding pairs of the first pilot symbols, e.g. first pilot symbol 20 and 21 or first pilot symbol 20 and 23. Thus, orthogonality in the frequency as well as in the time dimension is ensured.

The same is essentially true for the pilot symbol pattern shown in figure 4B, which corresponds to the pilot symbol pattern shown in figure 3B. Similarly, the pilot symbols of the pilot symbol pattern shown in figure 4B are alternatingly identical and orthogonal (inverse complex) to the corresponding first pilot symbols shown in figure 3B.

The pilot symbol scheme proposed by the present invention can be applied to any linear channel estimation algorithm in wireless OFDM communications. For the sake of clarity, a simple two pilot symbol average based channel estimation algorithm for the pilot symbol patterns of figure 3A and figure 4A is used as an example in the following further detailed description.

Assuming that the complex values of all first pilot symbols 20, 21, ..., 28 and the corresponding second pilot symbols having the identical value, i.e. second pilot symbols 42, 44, 47, 50, 52, ..., is A. The complex value of the second pilot symbols 43, 46, 48, 51, ..., having a corresponding orthogonal value is then -A. For all the data symbols between the succeeding pilot symbols 20 and 21 or 42 and 43, respective channel estimation values for the first (non-diversity) antenna 5 and the second (diversity) antenna 6 should be obtained reliably so that the STTD scheme can be applied.

As stated above, the antenna 11 and the receiving means 12 of the mobile terminal 10 receive the first and the second pilot symbols as superimposed or combined pilot symbols. Thus, let y_1 and y_2 be the received values from the first 20, 21 and the second 42, 43 pilot symbols. Since the time delay between the first and the second antenna 5, 6 is negligible, the following equations are valid:

$$y_1 = A \times h_1^1 + A \times h_1^2 + n_1$$

and

$$y_2 = A \times h_2^1 - A \times h_2^2 + n_2,$$

whereby h_1^1 is the channel transfer function from the first antenna 5 to the receiving antenna 11 for the first pilot symbol 20 with value "A", h_1^2 is the channel transfer function from the second antenna 6 to the receiving antenna 11 for the corresponding second pilot symbol 42 with value "A", h_2^1 is the channel transfer function from the first antenna 5 to the receiving antenna 11 for the first pilot symbol 21 with value "A", and h_2^2 is the channel transfer function from the second antenna 6 to the receiving antenna 11 for the corresponding second pilot symbol 43 with value "-A". n_1 and n_2 are the noise values. If y_1+y_2 is used as the channel estimation for the first (non-diversity) antenna 5 and y_1-y_2 is used as the channel estimation for the second (diversity) antenna 6, the signals from the first and the second antenna can be differentiated, the cross-interference can be eliminated and a reliable channel estimation for both antennas 5 and 6 can be obtained in the processing means 14 of the mobile terminal 10, if the channel transfer function is assumed to be kept fixed within the interval between the preceding and the succeeding pilot symbols across the time dimension, i.e. $h_1^1 = h_2^1$ and $h_1^2 = h_2^2$.

Thus, in the mobile terminal 10 the signals from the first and the second transmitting antenna 5, 6 can be differentiated and consequently a separate channel estimation for

each antenna 5, 6 can be achieved. Since the pilot patterns of the first and the second pilot symbols are orthogonal, the cross-interference from the first and the second antenna 5 and 6, can be eliminated. Thus, a STTD scheme can be used in a high data rate OFDM wireless communication system. It is to be noted, that the idea of the present invention can also be applied to OFDM based broadband radio access networks (BRAN), like HIPERLAN Type 2 systems. In this case, the pilot symbols are transmitted in preamble parts of a respective data burst comprising a preamble part and a data part. The pilot symbols comprised in the respective preambles should be alternatively identical and orthogonal for the two transmitting antennas.